

Pulmonary Thromboendarterectomy

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Pulmonary thromboendarterectomy (PTE) is indicated for the relief of symptoms due to chronic thromboembolic pulmonary hypertension and in asymptomatic patients in whom pulmonary hypertension develops during exercise. The procedure is associated with significant and sustained improvement in pulmonary and right ventricular hemodynamics and pulmonary vascular resistance.^{1,2} Reported operative mortality ranges from 4.4 to 24% and is dependent on institutional experience.^{3,4} Operative mortality is 8.3% for our entire series and 4.0% for our last 50 consecutive patients. Actuarial survival has been reported as high as 91% and 86% at 3 and 5 years, respectively.⁵

Success of the operation depends on a number of critical factors: careful patient selection, understanding the patho-

logic process, performing the operation in a bloodless field and understanding the pulmonary artery anatomy. Histopathology is characterized by intimal and medial thickening, presumably due to chronic thromboembolism and inadequate fibrinolysis.⁶ Recognition of this important layer in the pulmonary artery is critical for both effective and safe conduct of the operation. Excellent visualization of the pulmonary artery lumen is essential to adequate resection. This is often obscured by bleeding from aortopulmonary collaterals. We take a stepwise approach this issue: during initial cooling after mobilizing the superior vena cava, the right pulmonary artery is opened. If bleeding is limited and visualization is good, systemic cooling is halted and thromboendarterectomy is performed. If this provides inadequate visualization, after continued systemic cooling, an aortic cross-clamp is applied; the heart is arrested with cold blood cardioplegia, and thromboendarterectomy is performed. Low-flow cardiopulmonary bypass can be used appropriate to systemic temperature to improve vision. Last, in the majority of the cases, complete circulatory arrest is necessary.

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Operative Technique

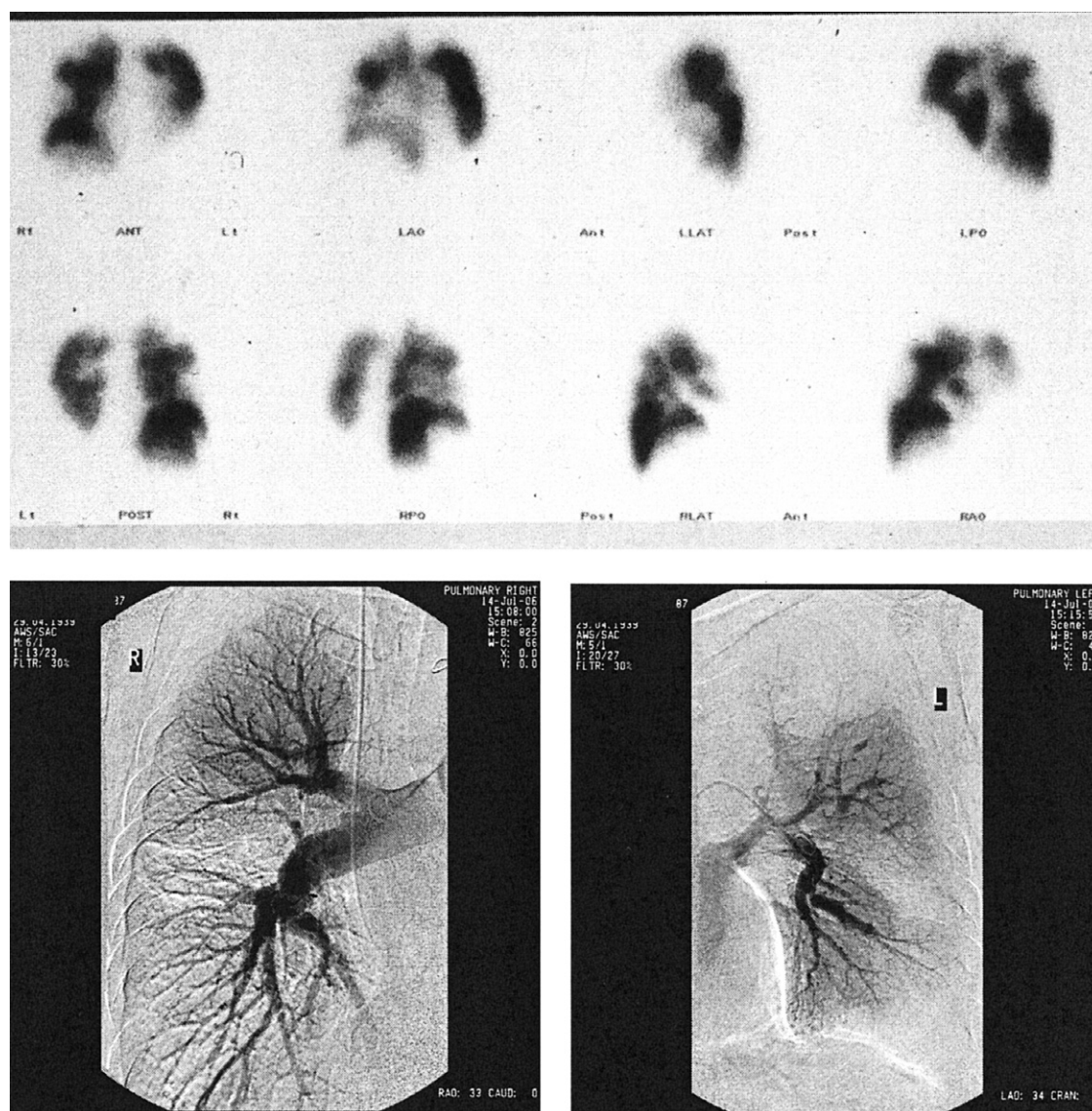


Figure 1 Proper patient selection is essential to identify those who will benefit most from surgery. Chest roentgenogram characteristically demonstrates areas of reduced vascularity and evidence of right heart enlargement. Ventilation-perfusion scans will often demonstrate multiple segmental ventilation-perfusion defects. Pulmonary angiography will demonstrate the characteristic features of this chronic process including strictures, webs, and obliterated pulmonary arteries.

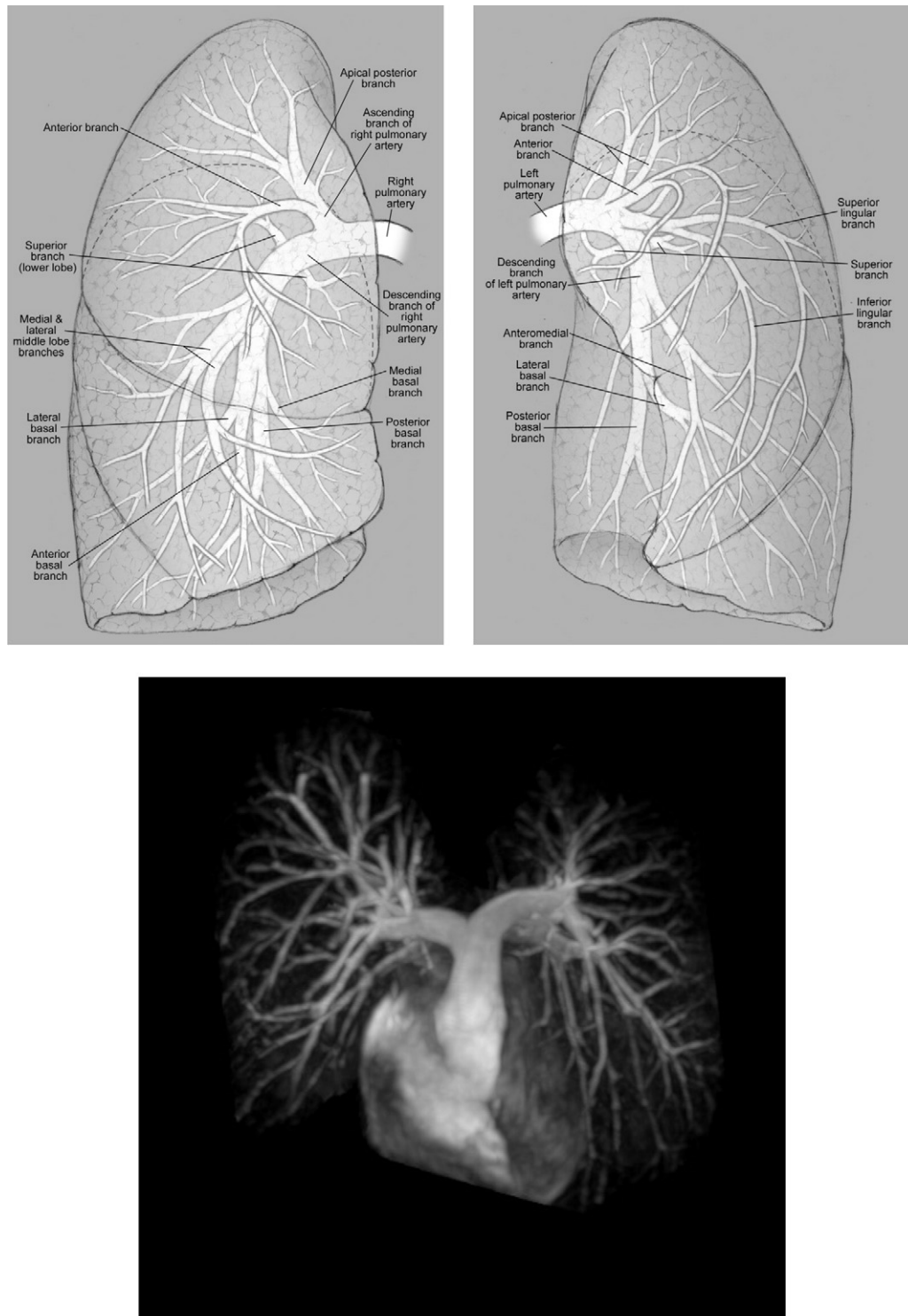


Figure 2 A sound knowledge of segmental pulmonary artery anatomy is essential for both a complete and a safe operation. Endarterectomy will be performed to the level of the subsegmental arteries. Lower figure represents magnetic resonance angiography 3D reconstruction of normal pulmonary arteries.

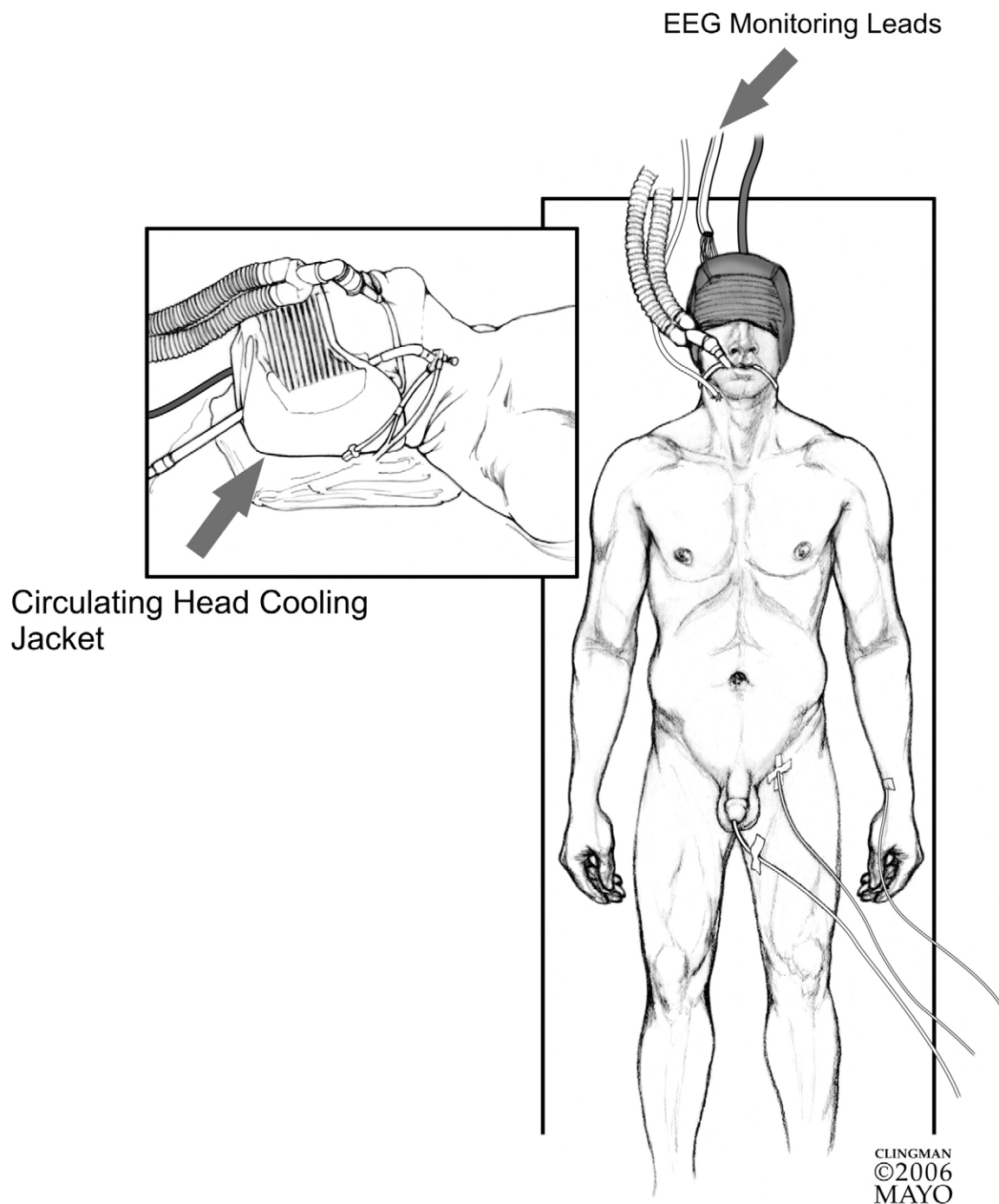


Figure 3 The patient is placed on the operating table in the supine position. A circulating cooling device is placed on the head (inset). In addition to a radial arterial line, a femoral arterial line is also placed to overcome the vasospasm associated with hypothermia. The patient is intubated with a single lumen endotracheal tube. A transesophageal echocardiogram (TEE) probe is placed (not shown). TEE is useful to exclude a patent foramen ovale without opening the right atrium. The bladder temperature probe is used to guide cooling to 18°C. Electroencephalogram (EEG) is used to guide cooling to EEG silence. Steroids, mannitol, and thiopental are not routinely used.

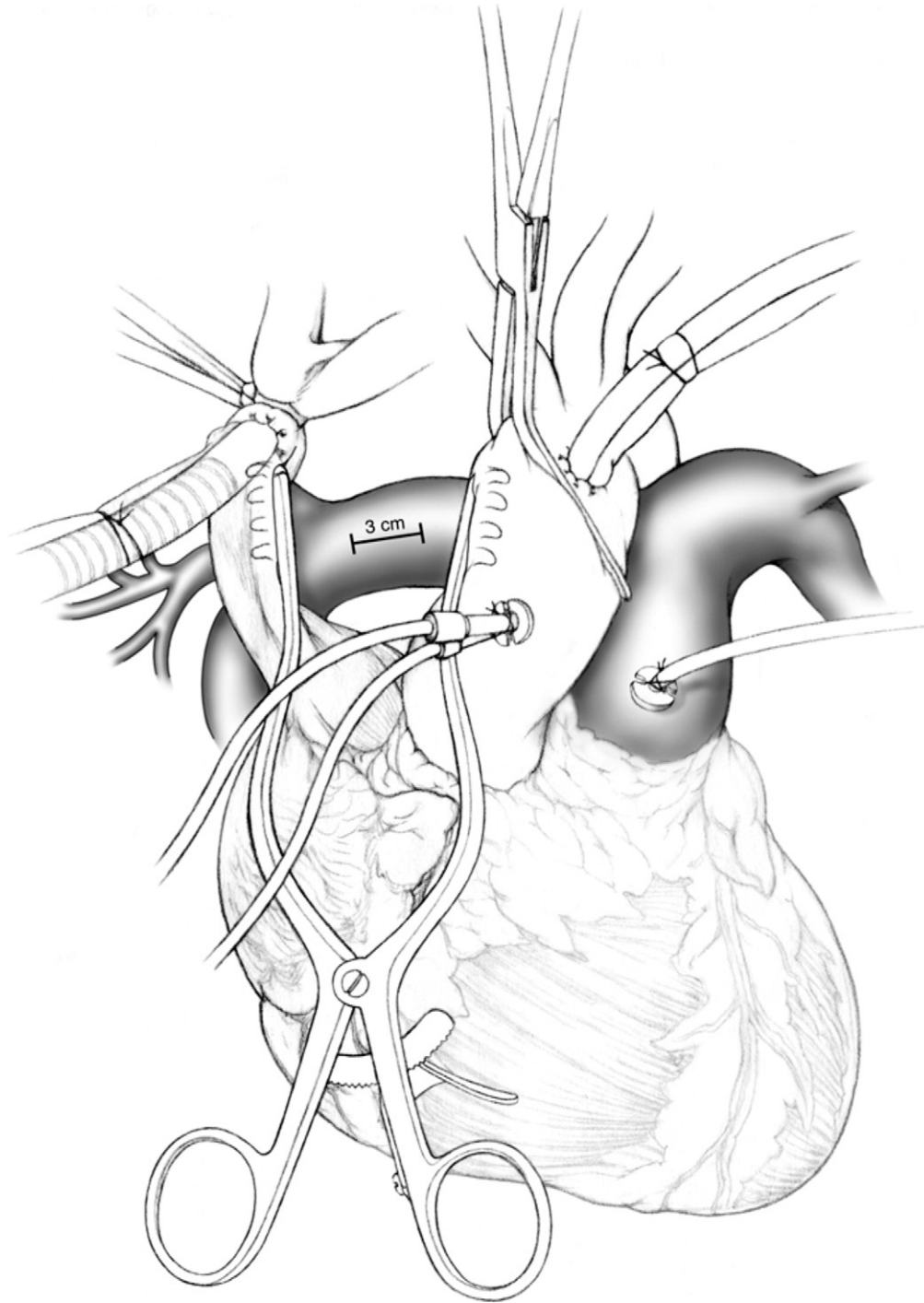


Figure 4 After median sternotomy, standard aortic cannulation and bicaval cannulation cardiopulmonary bypass is begun at 3.0 to 4.0 L/min. Systemic cooling is started to 18°C (bladder temperature). Cooling of the head is begun using a cold circulating head jacket. A vent is inserted into the proximal main pulmonary artery. Dissection is carried around the superior and inferior venae cavae around which snares are placed. Dissection is performed of the right main pulmonary artery, care being taken to avoid the right phrenic nerve. Caval snares are tightened and a 3-cm incision is made in the right main pulmonary artery extending down to the lower lobe artery.

By temporarily reducing the cardiopulmonary bypass flow, it is occasionally possible to perform the endarterectomy to the right pulmonary artery without circulatory arrest (10% cases). If extensive back bleeding persists at this point, the aorta is cross-clamped, and 10 mL/kg of cold blood cardioplegic solution is injected into the aortic root. Care is taken that the left ventricle does not distend. Topical cold saline is poured over the heart during the cardioplegia administration. A circulating cardiac cooling jacket is placed around the heart. If further inspection of the right pulmonary artery demonstrates minimal back bleeding at this point, circulatory arrest is not required. Temporary reduction in blood flow to 0.5 to 1 L/min (depending on body temperature) may be used intermittently (7% cases). If back bleeding remains excessive, cooling is continued until a temperature of 18°C is reached, cardiopulmonary bypass is discontinued, and the patient is temporarily exsanguinated (83% cases).

Concomitant procedures are performed while cooling. If a prior sternotomy has been performed and the right ventricle is distended, femoral–femoral bypass is used due to the high risk of right ventricular perforation. Prior inferior vena cava filter placement does not preclude femoral venous cannulation as a low-profile cannula can be advanced to the right atrium through the filter under fluoroscopic guidance.

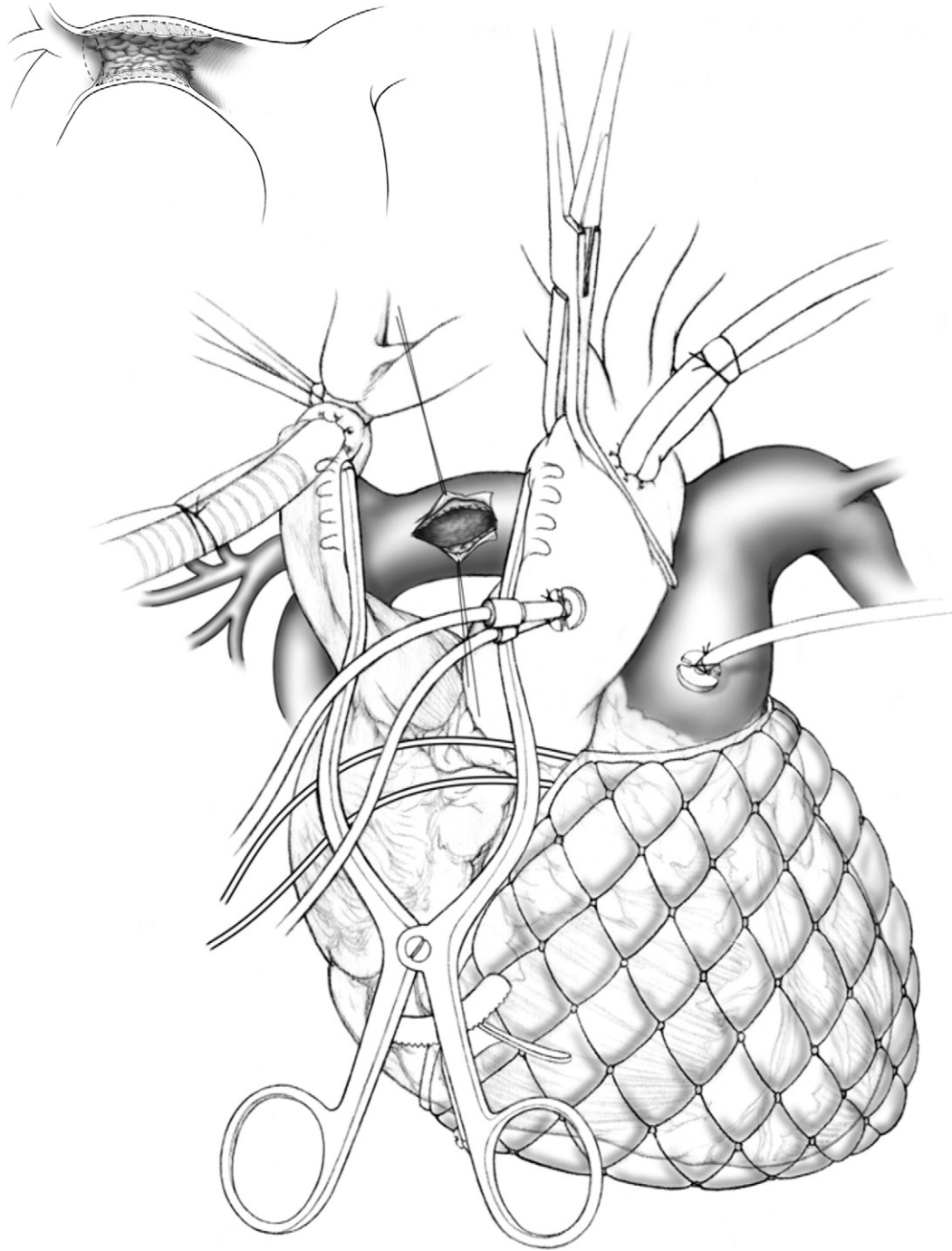


Figure 5 Thromboendarterectomy is begun on the right side. A cerebellar retractor is placed between the superior vena cava and the aorta to expose the right pulmonary artery in which a 3-cm longitudinal incision is made. 4-0 Prolene retention sutures retract the edges of the pulmonary artery. Often the lining of the artery appears relatively normal without obvious acute thrombus. Note the cardiac cooling jacket.

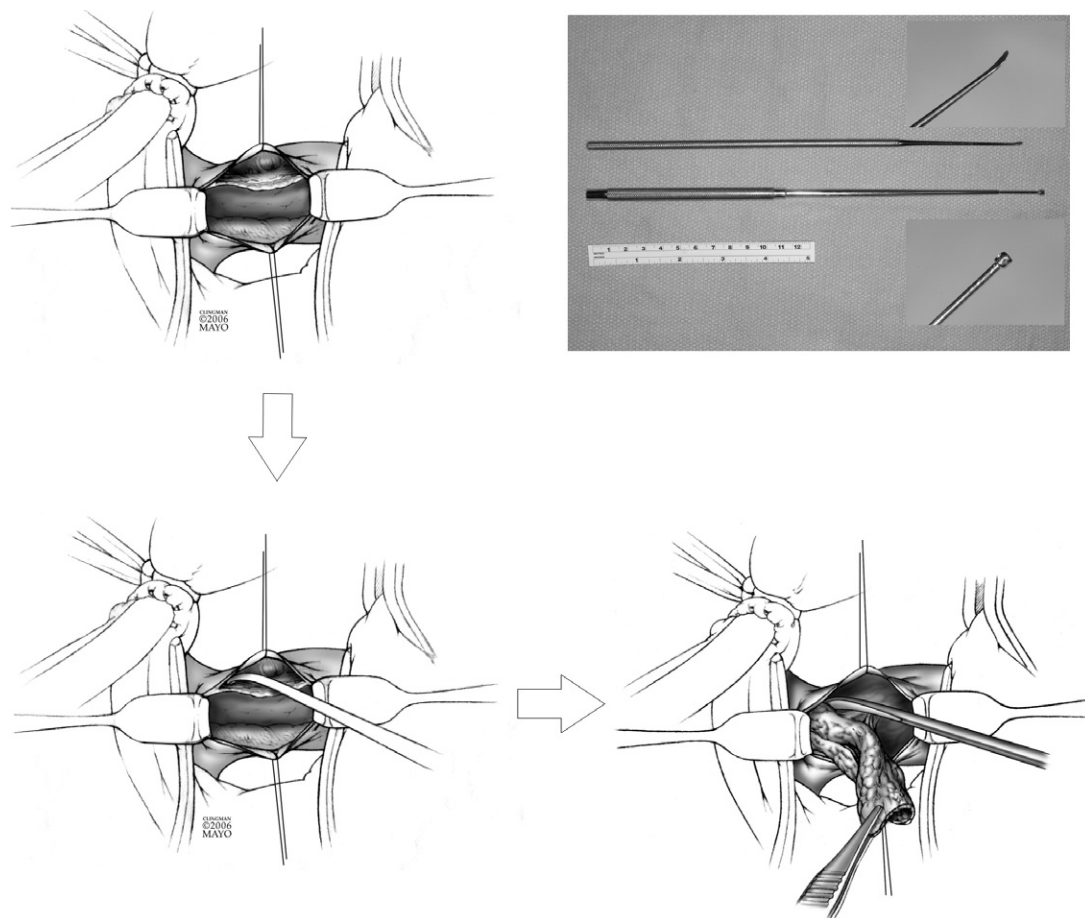


Figure 6 A dissection plane is initially created proximally at a location that is accessible to repair. Occasionally, however, it is necessary to begin the dissection more distally around the orifice of a segmental artery or where there is clearly a raised intima. With aspirating dissection instruments (inset) the dissection is extended distally to the segmental arteries. Extreme care is needed to remain within the medial layer of the vessel and great effort is made to remove the specimen contiguously. Hypothermic circulatory arrest is limited to 20 minutes at a time. Recirculation until venous saturations are $>90\%$ for 5 minutes is done between a maximum of three periods of arrest. We have seen no significant neurological complications using this technique.

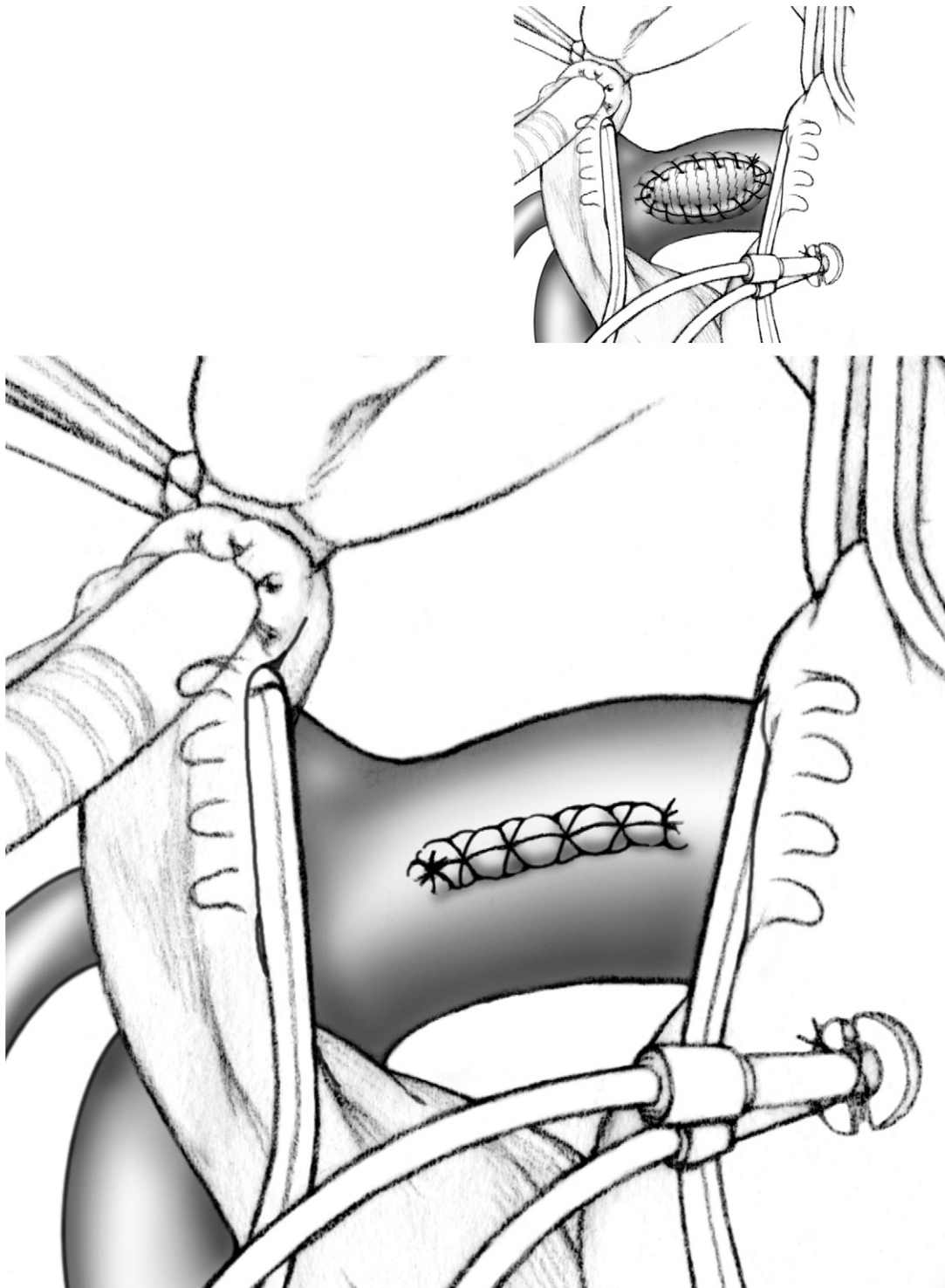


Figure 7 Right pulmonary artery is closed with running double-layer 6-0 Prolene suture. Occasionally, autologous pericardial patch closure is required. During closure, the patient is perfused with cold blood.

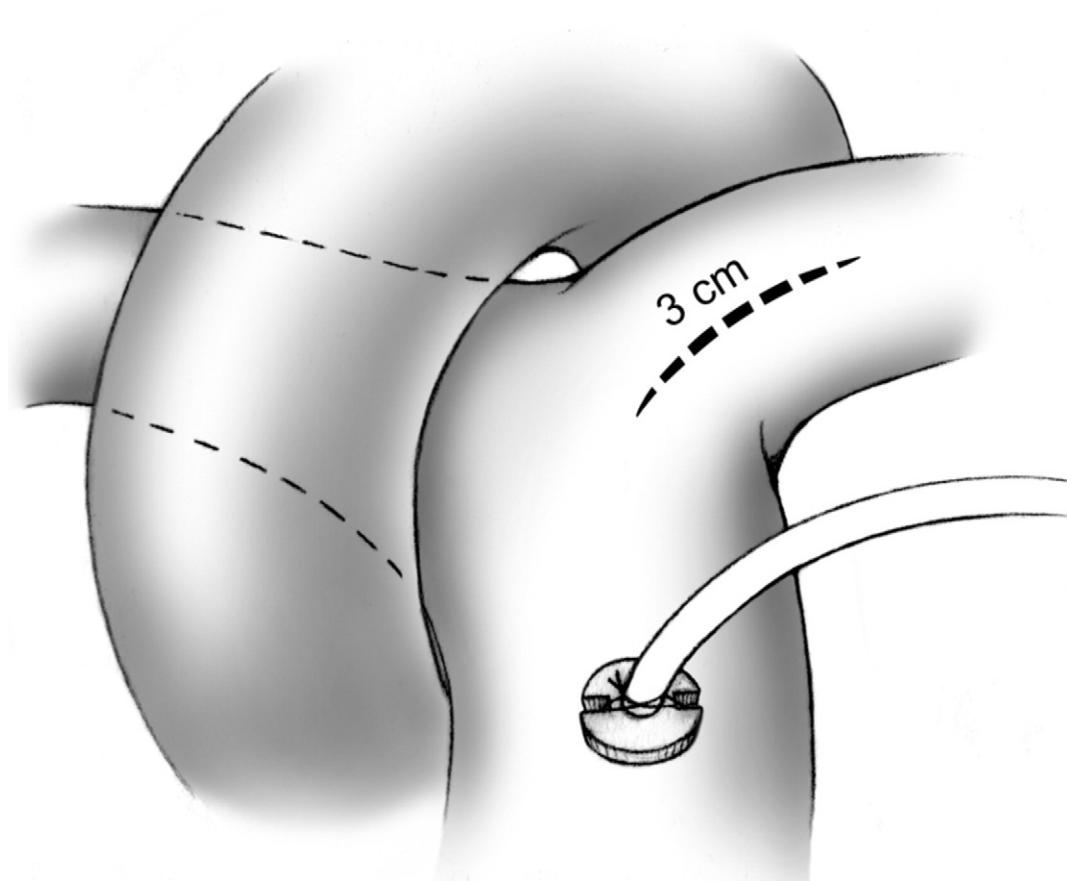


Figure 8 After reperfusing until the venous saturation approaches 90% for five minutes, the left pulmonary artery is opened longitudinally. Once again, hypothermic circulatory arrest is limited to 20 minutes. The pulmonary arteriotomy is started on the anterior surface of the pulmonary trunk and extended onto the left pulmonary artery. Endarterectomy is performed similar to the right side, beginning with the left upper lobe branch and extending distally.

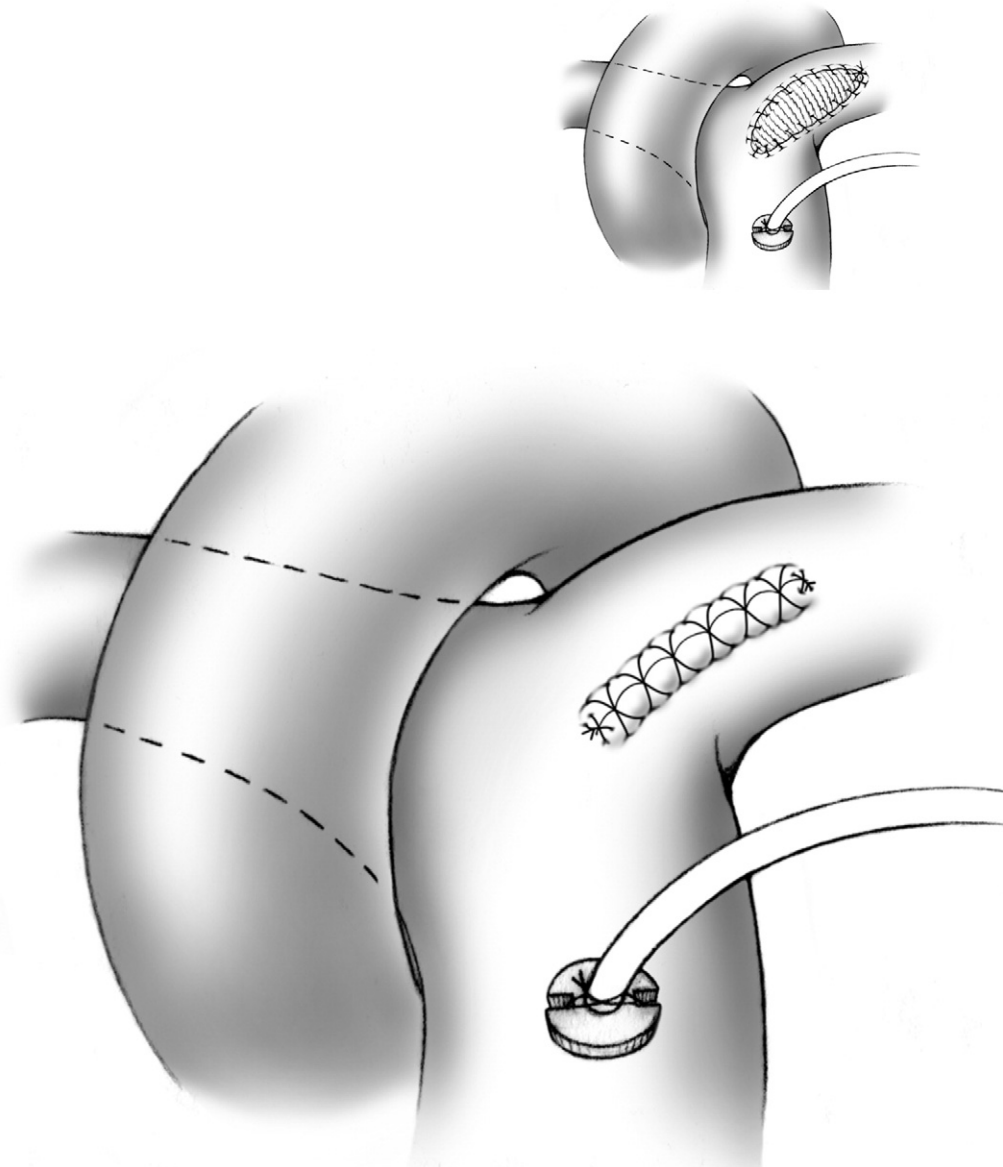


Figure 9 Once complete, the left pulmonary artery is closed in a similar fashion. Again, an autologous pericardial patch can be used to obtain tension-free closure. A left pleuropericardial window (3×3 cm) is created to prevent delayed pericardial effusions. Tricuspid regurgitation is not routinely addressed unless residual pulmonary hypertension exists.

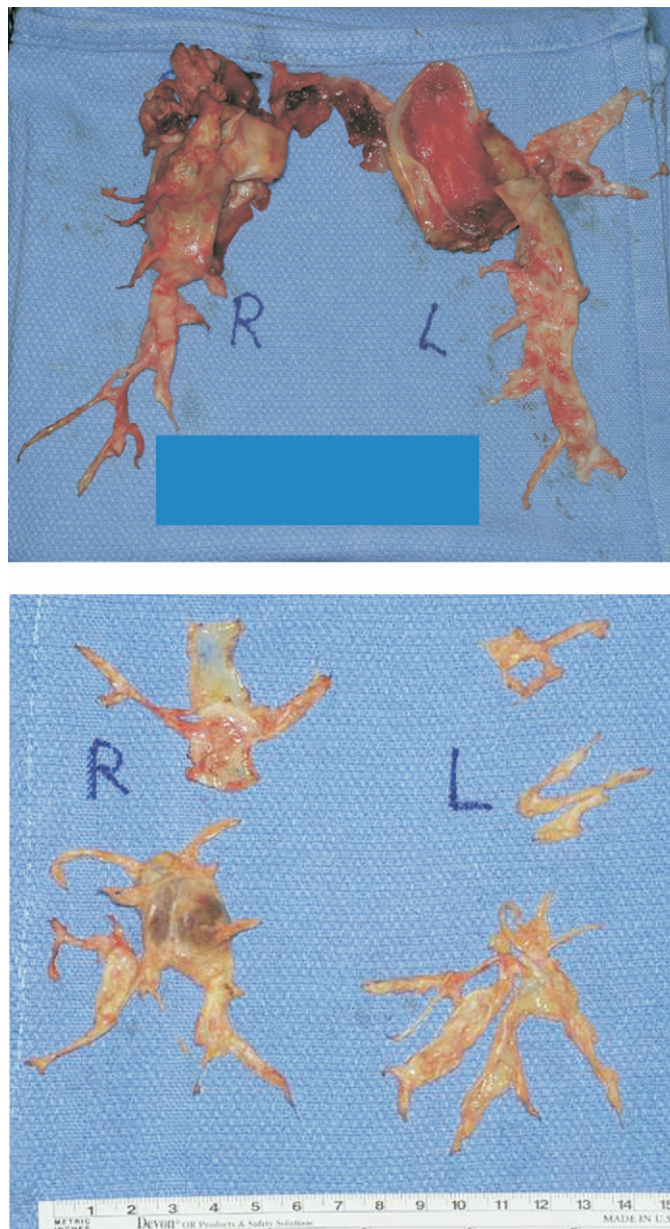


Figure 10 Representative specimens. (Color version of figure is available online at <http://www.us.elsevierhealth.com/optechstcvs>.)

Conclusions

Chronic thromboembolic pulmonary hypertension is believed to be the result of recurrent thromboembolism and inadequate fibrinolysis.⁷ This disease is associated with debilitating symptoms and reduced life expectancy. The 5-year survival in patients with mean pulmonary pressure > 30 mm Hg is 30% and only 10% for those with mean pulmonary pressure > 50 mm Hg.⁸ Pulmonary thromboendarterectomy is associated with significant improvements in pulmonary hemodynamics and right ventricular size.^{1,2} Success of operation depends on careful patient selection, understanding the pathologic process, a knowledge of pulmonary artery segmental anatomy, and meticulous surgical technique. Excel-

lent visualization of tissue planes in a dry operative field is essential.

Acknowledgment

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